SYSTEM AND METHOD FOR PERFORMING INTER-LAYER HANDOFF IN A HIERARCHICAL CELLULAR SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to wireless communications and, more particularly, to a call handoff or redirection system for a hierarchical cellular communications system.

2. Description of Related Art

A typical cellular communications system provides wireless communications service to a number of wireless or mobile units situated within a geographic region. The geographic region serviced by the cellular communications system is divided into spatially distinct areas called "cells." A conventional cellular communications system comprises a number of cell sites or base stations geographically distributed to support transmission and receipt of communication signals to and from the mobile units or wireless units. Each base station handles voice communications over a cell, and the overall coverage area for the cellular communications system is defined by the union of cells for all of the base stations, where the coverage areas for nearby base stations overlap to some degree to ensure (if possible) contiguous communications coverage within the outer boundaries of the system's coverage area.

As the demand for wireless service increases, techniques can be used to increase the capacity of the cellular system. For example, a hierarchical or overlay cellular system can be used where a network or layer of smaller sized cells are installed over the network or layer of larger cells. Using the smaller-sized cells increases capacity by increasing the number of radio channels servicing the geographic area. In a hierarchical cellular system, the majority of the traffic is serviced on the network or layers of smaller-sized cells, but if the wireless unit is moving rapidly, thereby requiring numerous handoffs in the smaller cell network, the wireless unit is placed on the network or layer of larger-sized cells.

Summary of the Invention

To take advantage of hierarchical cell layers, an inter-layer handoff system determines a cell layer for servicing a wireless unit at least as a function of the duration that the wireless unit is in a cell or set of cells of a cell layer. For example, as a function of the duration that the wireless unit is in the cell or set of cells for a first cell layer, a determination is made as to whether the wireless unit should be serviced by a cell or set of cells of a second cell layer. As such, wireless units moving at higher speeds which will be handed off frequently in a smaller cell layer(s) are serviced by a larger cell layer(s). Thus, the hierarchical cellular communications system can have the increased capacity provided by the smaller cell layer(s) while reducing the number of handoffs which would occur of the faster moving wireless units in the smaller cell layer(s). In certain embodiments, a timer starts when the wireless unit connects to a cell in a first layer, and the timer stops when the wireless unit disconnects from the cell. Depending on the amount of time that the wireless unit is in the cell of the first layer or a function thereof, the inter-layer handoff system determines whether the wireless unit should be serviced by another cell layer. For example, the network can compare a timer value(s) or a function thereof with threshold value(s) which are chosen such that the frequency of handoffs are below a certain level at each cell layer.

Brief Description of the Drawings

Other aspects and advantages of the present invention may become apparent upon reading the following detailed description and upon reference to the drawings in which:

FIG. 1 shows a general diagram of a hierarchical cellular communications system in which the inter-layer handoff system according to the principles of the present invention can be used; and

FIG. 2 shows a general flow diagram of an embodiment of an inter-layer handoff system according to the principles of the present invention.

Detailed Description

Illustrative embodiments of the inter-layer handoff control system are described with respect to a hierarchical cellular system having cell layers of different size cells overlaid over at least portions of the same geographic service area.

FIG. 1 depicts a diagram of a portion of a hierarchical cellular communications system 10, which provides wireless communications service to a number of wireless or mobile units 12a-c, that are situated within the geographic service area of the system 10. The geographic region serviced by the cellular communications system is divided into spatially distinct areas called "cells." In the geographic service area of the hierarchical system 10, the wireless unit 12a is serviced by a macro-cell layer 14a of macro-cell(s) 16 through a cell site or base station 24. A micro-cell layer 14b of micro-cells 18a-g is overlaid on the macro-cell layer 14a. The micro-cell layer 14b provides service through cell sites or base stations 26a-g to wireless units in at least a portion of the same geographic service area serviced by the macro-cell layer 14a. For example, the wireless unit 12b is being serviced by the micro-cell layer 14b through the base station 26a in the micro-cell 18a. Finally, a pico-cell layer 14c of pico-cells 20a-w is overlaid on the micro-cell layer 14b and provides service through cell sites or base stations 28a-w to wireless units in at least a portion of the same geographic service area serviced by the micro-cell layer 14b. For example, the wireless unit 12c is being serviced by the pico-cell layer 14c through the base station 28a in the micro-cell 20a.

A base station comprises the radios and antennas that the base station uses to communicate with the wireless units in the corresponding cell. The base station and a wireless unit communicate voice and/or data over a forward link and a reverse link, wherein the forward link carries communication signals over at least one forward channel from the base station to the wireless unit and the reverse link carries communication signals on at least one reverse channel from the wireless unit to the base station. There are many different schemes for defining forward and reverse link

channels for a cellular telephone system, including TDMA (time-division multiple access), FDMA (frequency-division multiple access or AMPS), and CDMA (code-division multiple access) schemes.

The base station also comprises the transmission equipment that the base station uses to communicate with a Mobile Switching Center (MSC) 30. The Mobile Switching Center 30 is responsible for, among other things, establishing and maintaining calls between the wireless units, calls between a wireless unit and a wireline unit (e.g., wireline unit 32) via a public switched telephone network (PSTN) 34 connected to the MSC 30 and connections between the wireless units and a packet data network 36. In certain embodiments, the MSC 30 is connected to a plurality of base stations that are dispersed throughout the geographic region serviced by the MSC 30 and to the PSTN 34 and/or the packet data network (PDN) 36, such as the Internet. The MSC 30 is connected to several databases, including a home location register (HLR) 38 containing subscriber information and location information for all wireless units which reside in the geographic region of the MSC 30. A typical base station comprises a base station controller (BSC) which administers the radio resources for the base station and relays information to the MSC. Depending on the embodiment, the BSC can be a separate base station controller (BSC) 40 connected to several base stations in a cell layer or in different cell layers which administers the radio resources for the base stations and relays information to the MSC 30. Additionally, depending on the embodiment, a separate MSC 42 can handle different cell layers in the hierarchical cell structure.

Within a cell layer in a hierarchical cellular system using TDMA or AMPS, when a wireless unit is experiencing poor voice/data quality and is close to being dropped, the wireless unit is handed off to another cell site or base station in the cell layer that can better service the call. The MSC 30 switches a call between base stations in real time as the wireless unit 12 moves between cells, referred to as a hard handoff. In CDMA communications, the wireless unit searches for pilot signals of base stations on an active set, a candidate set and a neighbor set. The active set is the

set of base stations through which active communications is established. The neighbor set is the set of base stations surrounding an active base station having some probability of having a signal strength of sufficient level to establish communications, and the candidate set is a set of base stations having a pilot signal strength at a sufficient level to establish communication with the wireless unit with a probability close to the active set.

The wireless unit measures the signal strengths of the pilot signals and provides the pilot signal measurements in a pilot strength measurement message (PSMM) to the wireless communications system through a serving base station. The wireless unit determines which base stations are in the candidate set based on the pilot signal strength measurements. The wireless unit sends the pilot signal measurements for the candidate and active base stations in the PSMM. When a pilot signal of a base station in the neighbor set exceeds a predetermined threshold level, the base station is added to the candidate set. When the wireless unit detects a pilot of sufficient strength which is associated with a base station in the candidate set, the wireless communications system determines whether to update the active set and assign a traffic channel from the base station to the wireless unit. The wireless unit is said to be in soft handoff if it is assigned traffic channels from more than one base station. A handoff can refer to when the base station(s) in the active set and/or in selected or current cell layer(s) changes or changes in a certain way.

In the hierarchical cellular system of FIG. 1, each cell layer 14a-c can operate independent of the other cell layers 14a-c. For example, if the hierarchical cellular system 10 uses TDMA or AMPS, each cell layer 14a-c can use its own set of frequencies with its own frequency reuse plan. In CDMA communications, different channels are distinguished by different spreading sequences that are used to encode different voice-based streams, which may then be modulated on the same carrier frequency for simultaneous transmission. A receiver can recover a particular voice-based stream from a received signal using the appropriate spreading sequence to decode the received signal. If the hierarchical cellular system 10 uses CDMA

communications, each cell layer 14a-c can use a different carrier frequency, such as carrier A for the macro-cell layer 14a, carrier B for the micro-cell layer 14b and carrier C for the pico-cell layer 14c. In alternative embodiments, different cell layers could use different schemes for defining communications channels. For example, cell layer 14a could use AMPS while cell layer 14b could use CDMA. Depending on the embodiment, a wireless unit could be in soft handoff with base stations of different cell layers 14a-c.

The hierarchical cellular system increases capacity by increasing the number of radio channels servicing the geographic area. In a hierarchical cellular system employing frequency reuse, such as in TDMA, GSM or AMPS, the frequencies are split between the different cell layers. The overall traffic density is greater because 1) the overlay (smaller cell layer(s)) is dense and 2) the overlay enjoys proportionately higher reuse than the underlay (larger cell layer(s)). Additionally, the layer(s) of smaller cells can enjoy a better frequency reuse than the layers(s) of larger cells because of local conditions, such as buildings, and the low/directional micro-cell power reduces the co-channel interference problem. In a CDMA system, the traffic density is also increased, but this increase is due to the higher density of cells not typically due to the frequency reuse.

When a wireless unit attempts to access the hierarchical cell system, an initial determination is made as to which cell layer is to service a wireless unit. This determination can be made in different ways. The initial cell layer can be established based on previous usage pattern for the wireless unit, on the traffic load of the different layers, using a predetermined layer, and/or at subscription. For example, a wireless unit with a history of being handed off to macro-cell layers may be initially put in a macro-cell layer. Alternatively, a layer having the smallest, the largest or intermediate size cells could be selected as the default access layer, or the default access layer could depend on characteristics of the particular wireless unit and/or of the different layers. For example, wireless units capable of using new technology or

certain communications systems may access on smaller size cell layers while older model wireless units can access on larger size cell layers.

Once the wireless unit has access to the hierarchical cellular system, the inter-layer handoff system determines whether to perform an intra-layer hand-off as the wireless unit travels through the geographic service area. Fast traffic should be on a layer of larger cells, and slower traffic should be on a layer of smaller cells. If fast traffic gets on a layer of smaller cells, the wireless unit can be dropped because the intra-layer hand-offs cannot happen rapidly enough as the wireless unit travels through the small cells. Conversely, if slow traffic gets on a layer of larger cells, the increased capacity provided by the smaller size cell layers is being wasted.

Accordingly, in order to take advantage of the hierarchical cellular structure, the wireless units must be directed to the appropriate cell layer depending on the speed of travel. For example a wireless unit 12a on a highway would stay on the macro layer 14a but be handed off to the micro layer 14b upon exiting the highway and entering a downtown area. In contrast, the wireless unit 12a returning to the highway could not remain on the micro layer 14b because the wireless unit speed would make hand-offs between micro-cells (intra-cell layer hand-offs) difficult at best.

In the hierarchical cellular system 10, the traffic should be directed to the pico-cellular network or pico-cell layer 14c to take full advantage of the increased capacity of the pico-cellular network. However, if the wireless unit is moving at a rate which requires numerous handoffs in the pico-cellular network, thereby requiring increased processing and potentially dropped calls, the wireless unit can be placed on the micro-cellular network or micro-cell layer 14b. If the wireless unit is moving rapidly and requires numerous handoffs in the micro-cellular network 14b, the wireless unit can be placed on the macro-cellular network or macro-cell layer 14a.

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In accordance with principles of the present invention, the inter-layer handoff system monitors and/or responds to the duration of a wireless unit in a cell or set of cells of a first layer and/or the time intervals between certain changes in the cell or set

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of cells servicing the wireless unit. Wireless units that spend a long time within the cell(s) of the first layer can be presumed to be at a slower speed. If so, the an inter-cell layer handoff can be performed to direct the wireless unit to an upper cell layer of smaller-sized cells, such as the micro-cell layer 14b or the pico-cell layer 14c depending on embodiment and/or whether the wireless unit is in the macro-cell layer 14a or the micro-cell layer 14b prior to the inter-layer handoff. Wireless units that spend a short time within the cell(s) of the first layer can be presumed to be at a higher speed, and the hierarchical cellular system performs an inter-cell handoff to a lower cell layer of larger-sized cells, such as the micro-cell layer 14b or the macro-cell layer 14a depending on the embodiment and/or whether the wireless unit is in the micro-cell layer 14b or the pico-cell layer 14c prior to the inter-layer handoff. Depending on the embodiment, the inter-layer handoff system could have multiple threshold levels which could enable an inter-layer handoff between the macro layer 14a and the pico-cell layer 14c.

FIG. 2 shows a general flow diagram of an embodiment of the inter-layer handoff system or portion thereof according to principles of the present invention which could be used to direct a wireless unit in a first cell layer, such as the micro-cell layer 14b in the hierarchical cellular system described in FIG. 1, to a second cell layer. Different embodiments of the inter-layer handoff system can be used for different layers in a hierarchical cellular system of at least two layers making different handoff determination for each layer and/or using additional threshold(s), different thresholds or manners of determining timer values. A wireless unit originates or terminates a call at block 50 using a cell of a selected cell layer. The selected cell layer can be chosen at random (for example, with weightings appropriate to the proportions of the various speeds), the least loaded layer, the lowest layer (such as the macro layer 14a in FIG. 1), any intermediate layer(s) (such as the micro-cell layer 14b of FIG. 1), the highest layer (such as the pico-cell layer 14c of FIG. 1), or as mentioned above based on the particular wireless unit (for example due to layer usage history or a decision made at subscription) or on the geographic service area. Depending on the multiple

access system used by the hierarchical cellular system, the origination/termination of a call through the cell of the selected cell layer would proceed as performed by a conventional cellular system with any additional system or wireless unit processing to avoid selection of base stations in other or certain cell layers as would be understood by one of skill in the art.

Once the wireless unit originates/terminates a call (establishes a connection with cell of selected cell layer) through the hierarchical cellular system, a network timer is started at block 52. The timer measures the duration of the call through the current cell of the selected layer. In the case of spread spectrum or CDMA systems, such as IS-95, cdma2000, Universal Mobile Telecommunications Service (UMTS), this could correspond to a current set of cells in the active set for the selected cell layer and/or in a different cell layer(s) with which the wireless unit is in soft hand-off. Alternatively, the timer or timer(s) corresponding to particular cell(s) or a set of cell(s) can start when all, a majority or any of cells which are in the active set and/or in the selected or current cell layer are replaced by new cell(s) in the active set and/or in the selected or current cell layer. At block 54, the call progresses until the inter-layer handoff system determines at block 56 if a intra-layer handoff trigger has occurred. Depending on the embodiment, an intra-layer hand-off trigger can occur when a hard handoff to a different base station occurs or is to occur. Alternatively, depending on the embodiment, a handoff trigger for the purposes of the inter-layer handoff system can occur when the active set and/or all, a majority or any cells in the selected or current cell layer changes or is to change, for example when the entire active set (or other sets), a majority of the active set (or other sets) or any portion of the active set (or other sets) changes. Depending on the embodiment, the active set (or other sets) can include base stations in different or only the same cell layer.

If no handoff trigger occurs, the inter-layer handoff system determines at block 58 if the timer is greater than a timer threshold level, such as threshold_up, for the current layer. If not, the call progresses in block 54. If so, the wireless unit has not been handed off for a period of time which the system has determined should trigger

an inter-layer handoff at block 60 to a layer of smaller cells. For example, depending on the embodiment and/or whether the current or selected cell layer is the macro-cell layer 14a (FIG. 1) or the micro-cell layer 14b, the inter-layer handoff system hands off the wireless unit to the micro-cell layer 14b (FIG. 1) or pico-cell layer 14c (FIG. 1). After the inter-layer handoff, the network timer is restarted at block 52. If the wireless unit is currently in the uppermost layer, such as the pico-cell layer 14c, the wireless unit remains in the uppermost layer.

If, at block 56, the inter-layer handoff system determines the occurrence of a handoff trigger, the timer is stopped at block 62 and the timer value is compared to a first threshold value, such as threshold_up, at block 66 for the current layer. If the timer is greater than or equal to the first threshold value, the wireless unit is moving and has been in the cell for a period of time which the system has determined should trigger an interlayer handoff at block 60 to a layer of smaller-sized cells. For example, depending on the embodiment and/or whether the current cell layer is the macro-cell layer 14a (FIG. 1) or the micro-cell layer 14b, the inter-layer handoff system hands off the wireless unit to the micro-cell layer 14b (FIG. 1) or pico-cell layer 14c (FIG. 1). After the inter-layer handoff, the network timer is restarted at block 52. If the wireless unit is currently in the uppermost layer, such as the pico-cell layer 14c, the wireless unit must remain in the uppermost layer. In this embodiment, the decision block 66 may be redundant with block 58 if the timer threshold level is the same as the first threshold value and/or the timer and timer values are determined in the same way. As such, depending on the embodiment, the block 66 can be removed, and the block 62 could proceed to block 68.

If the timer value is less than the first threshold value (or after a handoff trigger at block 56 without the timer threshold being triggered at 58 depending on the embodiment), the inter-layer handoff system compares the timer value to a second threshold, such as threshold_down, for the current cell layer at block 68. If the timer value is less than the second threshold, the wireless unit is moving rapidly and handing off between the cells of the current layer at too fast a rate. Accordingly, the

inter-layer handoff system triggers an interlayer handoff at block 70 to a lower layer of larger-sized cells. For example, depending on the embodiment and/or whether the current cell layer is the pico-cell layer 14c (FIG. 1) or the micro-cell layer 14b, the inter-layer handoff system hands off the wireless unit to the micro-cell layer 14b (FIG. 1) or the macro-cell layer 14a (FIG. 1). If the wireless unit is currently in the lowest layer, such as the macro-cell layer 14a, the wireless unit must remain in the lowest layer. After the inter-layer handoff, the network timer is restarted at block 52.

If the timer value is greater than or equal to the second threshold, the wireless unit is moving at a rate at which the wireless unit is handing off between the cells of the current layer at an acceptable rate. Accordingly, the inter-layer handoff system maintains the wireless unit in the current layer at block 72. The timer value can be the amount of time that the wireless unit is served by a cell in the first layer before being handed off to another cell in the first layer, and the timer value is compared to threshold values after each handoff trigger. However, the timer value compared to the thresholds at the blocks 66 and 68 could be timer values calculated as a function of previous amounts of time between intra-layer handoffs for the wireless unit, for example an average or weighted average of measured amounts of time between intra-layer handoffs over several intra-layer handoffs or previous timer events or using Infinite Impulse Response (IIR) filtering. After such information is obtained, the system makes a decision depending on its timer value(s) reflecting wireless unit activity in previous cells either to redirect the wireless unit to a more appropriate layer or to stay in the current layer.

As mentioned above, the timer values can be calculated as a function of previous timer values over a number of intra-layer handoffs. As such, the timer value used in making the inter-layer handoff determination at blocks 66 and 68 can be calculated or updated after each intra-layer handoff or after a number of intra-layer handoffs. The inter-layer handoff determination at blocks 66 and 68 can also be made after each handoff trigger and/or after a number of intra-layer handoffs depending on the embodiment. If no intra-layer handoff occurs while the timer threshold level is

exceeded at block 58, the inter-layer handoff system can perform an inter-layer handoff to a layer of smaller-sized cells.

Thus, the inter-layer handoff system for a hierarchical cell system provides increased capacity by directing handoffs to the smaller sized cells in upper layers of the hierarchical cell system when the wireless unit is not being handed off with enough frequency within cells of a current cell layer, for example when travelling at a slow speed. When the wireless unit is being handed off at a high rate with the cells of a current layer, for example when the wireless unit is travelling at high speed, the inter-layer handoff system can handoff the wireless unit to a layer of larger sized cells to reduce the number of intra-layer handoffs for the wireless unit. In the embodiment described above, the larger cells are described as being in lower layers and the smaller sized cells are described in upper layers, but other terminology could be used where upper layers are described as having the larger size cells and lower layers are described as having smaller size cells.

In addition to the embodiments described above, the inter-layer hand-off system for a hierarchical cellular system according to the principles of the present invention can be used with different cellular systems and configurations which omit and/or add components and/or use variations or portions of the described system or current cellular systems. For example, once the inter-layer handoff system determines that an interlayer handoff is to be performed for a wireless unit. The inter-layer handoff can be performed similar to an inter-system handoff as described in the standard identified as TIA/EIA-41-D entitled “Cellular Radiotelecommunications Intersystem Operations,” December 1997 (“IS-41”) or evolutions thereof and/or as an intra-system handoff as described in the time division multiple access system (TDMA) standard known as IS-136, the code division multiple access (CDMA) standard known as IS-95 or third generation (3G) evolutions thereof or the Global System for Mobiles (GSM) network as defined by the European Telecommunications Standard Institute (ETSI) or Universal Mobile Telecommunications Service (UMTS) evolutions thereof. Different ways of performing the inter-layer handoffs are possible as would be

understood by one of ordinary skill in the art. Moreover, an embodiment of the inter-layer handoff system has been described with reference to a spread spectrum, such as a CDMA or UMTS system, for the layers of the hierarchical cell system. Different multiple access systems, such as FDMA, TDMA CDMA or GSM, or different communications systems or evolutions thereof are possible for the different layers. For example, a lower layer could operate with a TDMA or CDMA system while an upper layer could operate with a 3G evolution thereof, or a lower layer could operate using a GSM system while an upper layer uses a UMTS evolution thereof.

It should be understood that different notations, references and characterizations of the various architecture blocks can be used. For example, the inter-layer handoff system can be used in a hierarchical cellular system having a plurality of cell layers of different size cells between layers. The inter-layer handoff system or portions thereof can be performed at the wireless unit, the base station(s), the base station controller(s), the MSC(s), the HLR(s), a visitor location register (VLR), an authentication center (AC) or other subsystem of the hierarchical cellular system. Additionally, an embodiment of the inter-layer handoff system has been described with respect to a current layer for the wireless unit within the hierarchical cellular system. Depending on the embodiment, the wireless unit could be in soft handoff with cells of different cell layers. Different timer and/or timer values can be used which correspond to the different base stations (cells) and/or cell layers. Timer(s) and/or timer value(s) corresponding to selected cell layer(s) could be used to determine inter-layer handoffs to cell(s) of another cell layer from at least the cell(s) of the selected layer(s) while base stations(s) in different cell layer(s) can remain in the active set or not.

In the embodiment described above, the determination as to whether an inter-layer handoff is to be performed is made at each intra-layer handoff. Depending on the embodiment, the inter-layer handoff system can make an inter-layer handoff determination after one or a number of intra-layer handoff based on the timer or timer values. The timer or timer values can be a function of the amount of time the wireless

unit is serviced by a cell(s) in a cell layer before being handed off to different cell(s) in the cell layer, such as averages, weighted averages or as a function of timer values over a number of intra-layer handoffs. The timer or timer value can be the amount of time being serviced by current cell(s) in a current or selected cell layer(s). In certain embodiments, timer refers to the amount of time being serviced by a current cell(s), and timer values refers to functions of the amount of time the wireless unit is serviced by a current cell(s) which includes the amount of time the wireless unit is serviced by a current cell(s).

The inter-layer handoff system can use different threshold value(s) for the different layers, and the described flow diagram can be different for different layers, and/or the inter-layer handoff system could use an indication of the current layer for the wireless unit each time a determination is made as to whether a inter-layer handoff should be made. Accordingly, depending on the embodiment for the inter-layer handoff system, the determination of the timer and/or other values, the threshold(s) being used and the determination whether to perform an inter-layer handoff can change depending on the cell layer(s) as would be understood by one of ordinary skill in the art with the benefit of this disclosure. It should be understood that the inter-layer handoff system and portions thereof can be implemented in processing circuitry such as application specific integrated circuits, software-driven processing circuitry, programmable logic devices, firmware, hardware or other arrangements of discrete components as would be understood by one of ordinary skill in the art with the benefit of this disclosure. What has been described is merely illustrative of the application of the principles of the present invention. Those skilled in the art will readily recognize that these and various other modifications, arrangements and methods can be made to the present invention without strictly following the exemplary applications illustrated and described herein and without departing from the spirit and scope of the present invention.